INTRODUCTION

Most combustion processes in industry (e.g., furnaces and engines) and nature (e.g., forest fires) are turbulent. Understanding the fundamental processes involved in turbulent combustion can lead to improved predictive capability and design of practical combustors resulting in enhanced efficiency and reduced pollutant formation. It can also lead to improved fire safety and fire fighting practices. Turbulent Gas-Jet Diffusion Flames (TGDF) is the first space experiment that will study these fundamental processes by obtaining data on the interaction of a well-defined and controlled vortex (the building block of turbulence) with a gas-jet diffusion flame (fig. 1). TGDF will be conducted in a Get Away Special (GAS) canister on the Space Shuttle *Columbia* during the STS–87 mission in November 1997. The experiment cannot be conducted under normal-gravity conditions on Earth due to the formation of buoyancy-induced vortices which interact both with the flame and with any imposed vortices.

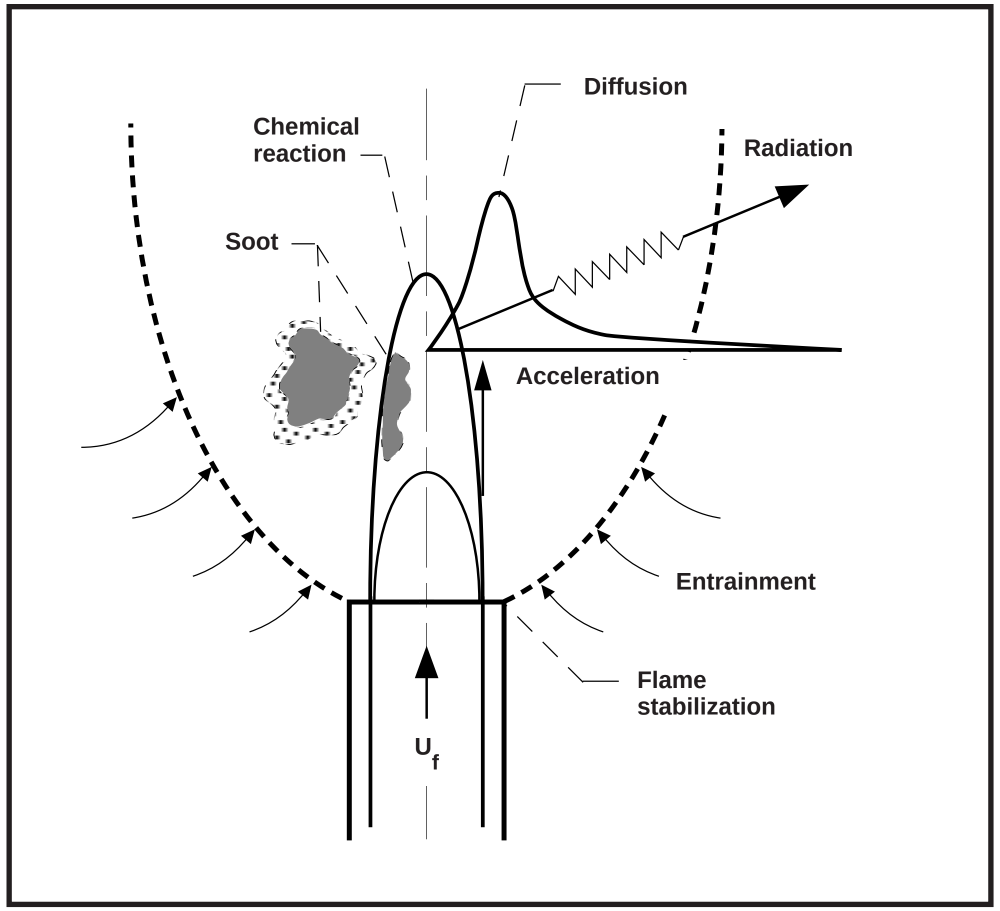

Figure 1.—Schematic of the structure of a gas-jet diffusion flame; a complex function of the depicted mechanisms.

SCIENCE OVERVIEW

The overall objective of the TGDF experiment is to gain an understanding of the characteristics of microgravity transitional and turbulent gas-jet diffusion flames by investigating the dynamics of vortex/flame interaction. The relevance of this study to Earth-based combustors may be understood by noting that in most practical combustors the velocity of the fuel (or air) jet is sufficiently high so that buoyancy effects are small. Unfortunately, at these high velocities, the flame structure becomes very complicated and cannot be resolved by existing techniques. In order to resolve the flame structure, the fuel velocity must be reduced; but, in this case, under Earth conditions, buoyant effects become dominant and the situation becomes much less relevant to practical conditions. By going to a microgravity environment, lower fuel velocities can be used without buoyant effects and the flame structure can be resolved.

In the TGDF experiment, the vortex/flame interaction is produced by imposing large-scale controlled vortices on a well-defined microgravity laminar diffusion flame. The imposed vortices are generated by an iris mechanism which periodically varies the open diameter of the iris around the base of the flame, causing flucuations in the entrained air flow. The primary parameter that will be varied is the frequency of the iris pulsations.

The specific objectives of TGDF are to gain an understanding of:

- The time-dependent effects at the frequency of the imposed disturbance including the spatial distribution of the vortex amplitude, the rate of convection of the vortex and the relative phases of flame shape, temperature, and radiation oscillations
- The possible vortex breakup or merging including the generation of harmonics and subharmonics of the vortex frequency
- The changes in time-averaged values of temperature, radiation, and flame shape as a result of the vortex-flame interactions

To accomplish these objectives, measurements will be made of temperature, flame radiation, and flame shape. Temperatures will be measured at various locations both inside and outside of the flame sheet by means of thermocouples. Flame radiation will be measured from flame slices as well as from the entire flame by means of thermopile radiometers. Flame shape will be obtained by means of two video cameras which will image the flame during the entire experiment. The sampling rates for these measurements will be in the range of 30-50 Hz. Since the frequencies of the imposed vortices are in the range of 1-5 Hz, these sampling rates are more than adequate to obtain the time-dependent behavior of the flame.

As shown in Figure 2, the obtained data will be of oscillatory character and, therefore, will be analyzed using Fourier techniques. Correlations between flame shape, temperature, radiation, and vortex motion will be obtained. From these correlations, the characteristics of the vortex/flame interactions can be deduced. These results will also be compared with a numerical model of the pulsed flame specifically developed for this experiment.

The numerical model utilizes a comprehensive transient Navier-Stokes formalism. The model provides predictions of the pressure, velocity, temperature, and species fields during the vortex/flame interactions. Both diffusion-controlled and kinetic-controlled combustion models can be used. The model will be validated by comparing its predictions with the obtained experimental data.

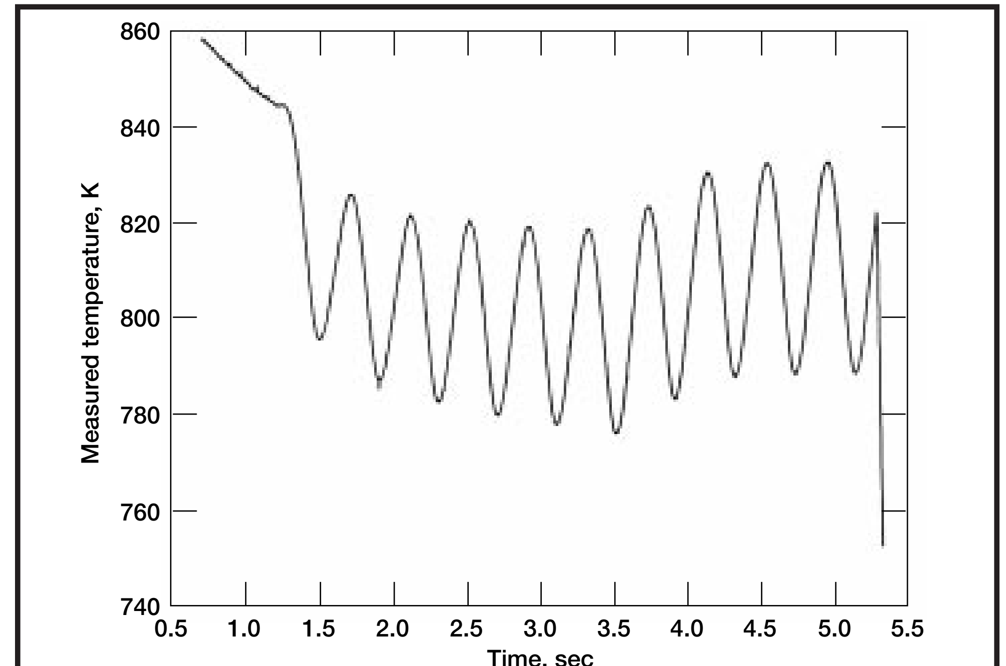

Figure 2.—Measured temperature at flame centerline during a drop test in the 5.18-Second Zero-Gravity Facility at NASA Lewis. The drop commenced at approximately time t = 0 seconds. The vortex generation mechanism commenced pulsing at 2.5 Hz at time t = 1.25 seconds.

TGDF HARDWARE DESCRIPTION

TGDF is a self-contained autonomous experiment flying as a GAS payload in the Space Shuttle bay. The experiment weighs 177 pounds and occupies 5 cubic feet. The hardware consists of two main subsystems: the instrumented combustion chamber and the supporting electronics. The electronics are located above the combustion chamber, and they are mechanically joined together by a support structure.

The combustion chamber contains the fuel supply system, igniter system, vortex generation mechanism, and science instrumentation. The latter includes two video cameras (one color, and one black and white), three radiometers, a thermocouple rake with eight type-K thermocouples, and three pressure transducers.

The supporting electronics include an 800-watt-hour silver-zinc battery, a power control unit, the igniter power supply, the data acquisition and control system, and two 8-mm video tape recorders.

Combustion Chamber

The nearly cylindrical combustion chamber is assembled from three pieces—a base plate, sidewall, and lid. The chamber provides a free volume of approximately 53 liters. It is equipped with an external thin-film heater for thermal control.

Fuel Supply System

The fuel supply system consists of a propane supply bottle, pressure transducers, a pressure regulator, fixed flow orifice, and two non-latching solenoid valves (in series) to control the fuel flow. The fuel nozzle has an internal diameter of 1.6 mm. The fuel is injected at a flow rate of 2 cc/sec (at 1 atm and 21 °C). The gaseous propane fuel (0.75 g) is contained in a 75-cc bottle at 5.4 atm. The system will produce a microgravity flame approximately 10 cm in height, and 4 cm in diameter.

Vortex Generation Mechanism

The vortex generator or flame disturbance mechanism consists of a microstepping driver/indexer and a stepper motor connected to an iris assembly. The iris mechanism will be modulated at frequencies of 1.5 Hz, 3 Hz, and 5 Hz to produce the large-scale, controlled disturbances required.

Science Instrumentation

Two non-collinear, orthogonal views of the flame region will be provided to verify the axisymmetric nature of the flame and disturbances. One black and white and one color video camera are used to image the gas-jet diffusion flame. The camera controllers are integrated, so they only require an external power supply. The black and white camera has a 2/3-inch format with 768 x 493 pixels, and 570 lines of resolution. The color camera has a 1/2-inch format with 682 x 492 pixels, and 430 lines of resolution.

Two recorders, ruggedized and vibration-isolated for flight conditions, will be used to record video data.

Temperature measurements in and near the flame will be made by a thermocouple rake which will be sampled at 50 Hz. The thermocouples are cantilevered in from the chamber wall. In addition, three thermistors will be used to monitor chamber wall temperatures.

Three radiometers (two slice and one global) will measure the radiation emitted from the flame. Each uses a detector which will be sampled at 50 Hz. The radiometers provide a signal of 0-25 mV which is amplified to 0-5 V for processing by the Data Acquisition and Control System (DACS). The slice radiometers consist of a narrow-bandwidth filter, a plano-cylindrical lens, a biconvex lens, and a thermopile detector. The global radiometer consists of a neutral-density filter and a thermopile detector. Each detector has a KBr (potassium bromide) window.

Igniter Power Supply

The igniter power supply converts the 28-V-dc power from the power control unit to the 0-12 V needed for the igniter. The unit operates at a constant current (nominal setting of 2.25 amps). Voltage and current monitoring are implemented.

Data Acquisition And Control System (DACS)

Control of the experiment is executed using software stored in the DACS. All data except for video is collected and stored in the DACS. The DACS is a STD-BUS computer system with a 9-card backplane. Inside the combustion chamber are a custom thermocouple compensation board used for amplification of the thermocouple voltages, three custom radiometer amplifier boards, and a motor controller board.

Support Structure

The experiment support structure is fabricated from 6061–T6 aluminum and provides the main load bearing support for the other subsystems. The structure consists of an electronics shelf and a combustion chamber supported by vertical stringers. Ten stringers tie the electronics shelf to the GAS experiment mounting plate. Another 10 stringers tie the combustion chamber to the electronics shelf.

OPERATIONAL SCENARIO

The experiment will be enabled by the closure of the GAS canister barometric switch shortly after launch. This will cause the DACS to be powered ON. The DACS will control the combustion-chamber heaters as needed to maintain the chamber temperature above 12 °C.

A crewmember, or the DACS via a time default, will start the experiment operation. The fuel flow and the igniter will be activated. The fuel stream will be ignited above the nozzle tip. The ignitor will withdraw, and the flame will be allowed to stabilize.

Next, the disturbance mechanism iris will operate at the three preset frequencies with a 2-second iris adjusting period and a 5-second quiescent period between successive frequencies. This stage will last approximately 70 seconds. Following the final frequency, the iris will open to its maximum diameter.

During the next phase of the experiment, the disturbance mechanism will be dormant with the iris open at its maximum diameter. The data collection will continue for 3 minutes. At the end of this phase, all of the remaining fuel will have been burned, and the cameras and video recorders will be turned off. The final phase is the cool down of the combustion chamber. The experiment will continue to record data at a rate of once every 10 minutes from the thermocouples, pressure transducers, and the thermistors on the chamber wall.

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WWW SITES

TGDF Experiment
http://zeta.lerc.nasa.gov/expr2/gjdfe.htm

STS-87 Mission
http://www.ksc.nasa.gov/shuttle/missions/sts-87/mission-sts-87.html

Space Shuttle
http://shuttle.nasa.gov/

NASA
http://www.nasa.gov/

Lewis Research Center
http://www.lerc.nasa.gov/

Microgravity Science Division
http://zeta.lerc.nasa.gov/

Related Educational Sites
http://zeta.lerc.nasa.gov/new/school.htm
http://quest.arc.nasa.gov/shuttle/
http://liftoff.msfc.nasa.gov/
http://spacelink.nasa.gov/

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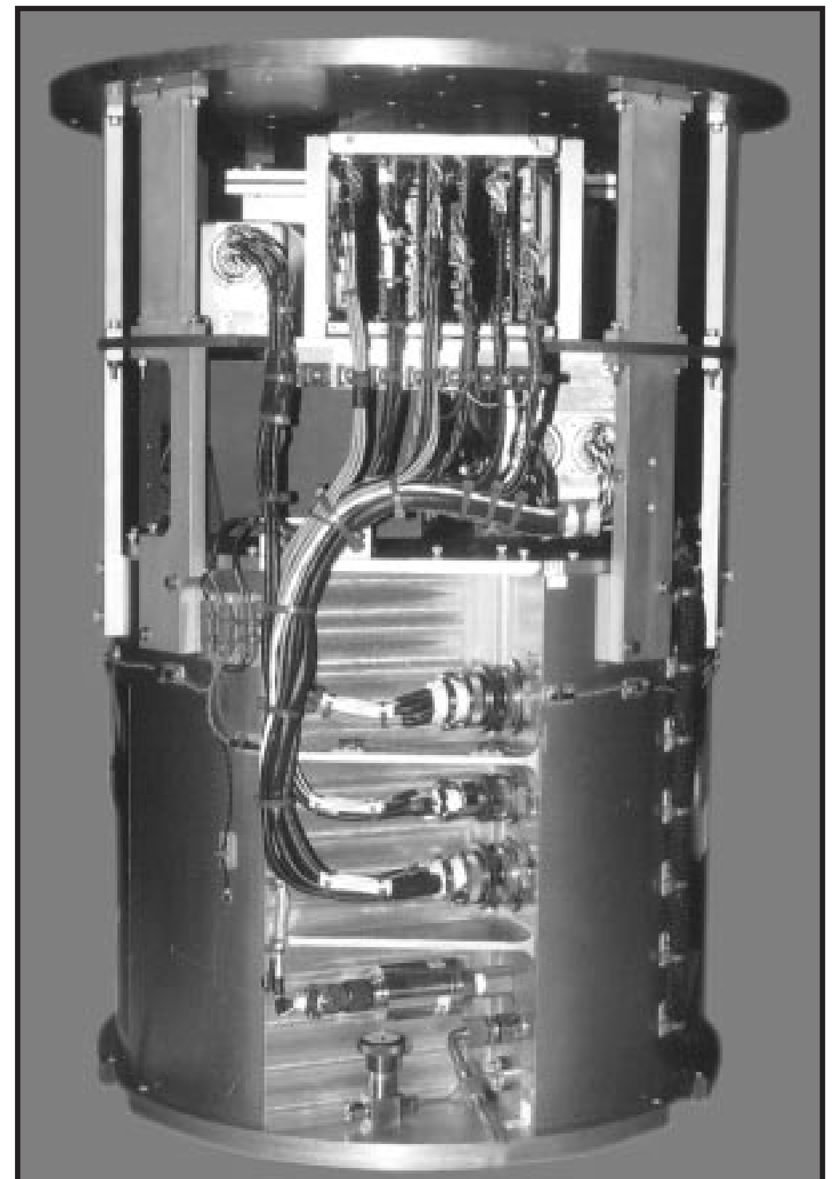
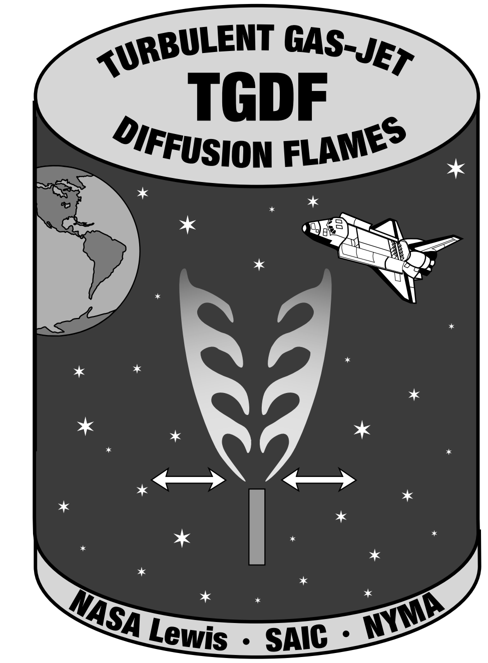
Turbulent Gas-Jet Diffusion Flames (TGDF)



Turbulent Gas-Jet Diffusion Flames (TGDF) experiment hardware.



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